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MUZZLE VELOCITY DROP IN WEAR-LIMITED ARMY GUNS

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) meg/srf

The XM201 series of 155mm propelling charges has been in engineering development for the past several years to replace the M119 propelling charge. The new propelling charges is required to last the same 5000 rounds as does the M119 charge fired from the M185 cannon. The basis for comparing the M119 charge and the developmental XM201 series of charges was a table of muzzle velocity drop, diameter increase, and round number for the M119 charge. The wear vs round number was taken from data obtained with M119 charges conditioned at (Cont'd)

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20. Abstract (Cont'd):

294K (70°F), velocity drop vs wear was calculated from data obtained in two separate tubes with propellant conditioned at 336K (145°F). Since the erosivity of the XM201 series was the only requirement the new charge needed to hurdle to complete development, an analysis was made of velocity drop and land diameter increase for Army wear-limited cannons to estimate the quality of the M119 data.

The analysis revealed that the muzzle velocity drop/initial velocity could be correlated to diameter increase/initial diameter. Data from one M185 cannon used for the M119 charge fell significantly off the curve for other cannons. The muzzle velocity drop vs round number listed in the 155mm firing tables is probably low. The analysis for M203 charges which were conditioned at 294 and 336K showed the muzzle velocity drop was similar for a given land diameter increase. Thus, the original basis for constructing the muzzle velocity drop vs round number table for the M119 charge was sound.

The analysis showed that projectiles with obturators and projectiles with oversized rotating bands compared to the M107 projectile produced lower muzzle velocity drop for a given state of wear. It was also shown that projectiles fired from the M199 cannon had lower muzzle velocity drop than the same projectiles fired from other 155mm guns. This was attributed to the unusual wear profile of the M199 cannon in which the grooves do not wear until the lands disappear. Such a wear profile would be expected to provide better obturation. The lowest rate of muzzle velocity drop was seen when the M483A1 projectiles were fired from the M199 cannon.

Obturators placed on the M107 projectile increased the muzzle velocity when the M107 was fired from a worn tube. The increase was not as great as that observed for the projectiles with oversized rotating bands. Hence, the rotating band design rather than the presence of obturators on the M483A1 seems to be the major factor for the lower rate of muzzle velocity decay as the gun tube wears.

Another factor which raises doubt about Table I is the type of gun used to generate the data. The muzzle velocity drop vs bore diameter was determined with two XM185 cannons; the bore diameter vs rounds fired was determined with four XM185 cannons and two M185 cannons. The chamber length and forcing cone taper differ for the XM185 and M185 cannons as shown in Table II along with the dimensions of the M199 cannon.

Given the weight of the data in Table I to assess whether 155mm propelling charges had satisfied development objectives, an analysis was made of muzzle velocity drop vs bore diameter for a number of Army guns. This report summarizes that analysis and some other observations and conclusions that became evident during the analysis.

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I. INTRODUCTION

The 155mm XM201E2 is a dual zone propelling charge that has been in engineering development for the past several years. The XM201E2, as part of a new family of charges, was also intended as a replacement for the single zone M119 charge. The XM201E2 is a base-ignited charge in contrast to the combined base and center-core igniter in the M119 charge which eases loading, assembly, and packing of the XM201E2 charge. This makes the XM201E2 charge cheaper to produce than the M119. In addition to cost, the XM201E2 exceeded all performance requirements except barrel life. The barrel life requirement was that the XM201E2 charge be no worse than when firing the M119 charge. The estimated barrel life for the 155mm M185 cannon was based on the data in Table I which came from the 155mm firing table[1]. The XM201E2 charge produced a comparable velocity drop in only 1000 rounds[2] as compared to 5000 for the M119.

Subsequent experiments[3,4] demonstrated that the TiO_2/wax liner in the XM201E2 charge was ineffective. It was also demonstrated that replacing the clean-burning igniter with black powder shortened the ignition delay and rendered the additive effective. The exact mechanism for this is still not completely understood. The igniter in the XM201E2 charge was subsequently modified by addition of black powder. Wear tests were then scheduled to see if the modified charges would satisfy the barrel life requirement.

It was learned that Table I was constructed from separate tests performed with charges conditioned at different temperatures. The round number <u>vs</u> bore diameter was determined with M119 charges conditioned at 294K (70°F). Velocity drop <u>vs</u> bore diameter was determined with M119 charges conditioned at 336K (145°F). In addition, the velocity drop for the XM185 cannons used in the high-temperature tests was different (18.0 m/s <u>vs</u> 5.2 m/s) for the same bore diameter increase of 1.90mm[5].

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1. *Firing Table, FT 155 AM-1.*

2. *J.A. Demaree, "155mm M185 Tube Wear Test of Charge Propelling XM201, Interim Report", JPG-76-601, June 1976.*

3. *J.R. Ward and T.L. Brosseau, "Effect of Wear-Reducing Additives on Heat Transfer Into the 155mm M185 Cannon", BRL Memorandum Report No. 1730, February 1977.* (AD #484693)

4. *F.A. Vassallo, "An Evaluation of Heat Transfer and Erosion in the 155mm M185 Cannon", Calspan Technical Report No. VL-5337-D-1, July 1976.*

5. *K.K. Bussell, "Tube Life Test of 155mm, SP, M109E1, XM185 Cannon Serial Number 1 and 2", YPG Firing Report No. 9613, July 1969.*

Another factor complicating the assessment of the data in Table I is that the chamber length and forcing cone taper differ for the XM185 and M185 cannons. The velocity drop vs bore diameter was done with two XM185 cannons. The bore diameter vs round number was determined from data for six tubes, two M185 cannons and four XM185 cannons[6]. Table II summarizes the differences between these two cannons along with equivalent data for the towed 155mm howitzer, the M199 cannon. The M199 cannon has a tapered chamber and the same shallow-taper forcing cone as the XM185 cannon. This prompted our examination of muzzle velocity drop as a function of barrel erosion to test how reasonable were the data for the M119 charge in the 155mm firing table, since successful development of the modified XM201E2 would depend on comparing wear test results with Table I. This report summarizes results and conclusions of that analysis.

TABLE I. Approximate Losses in Muzzle Velocity for the M119 Propelling Charge[1]

Number of Rounds	Land Diameter mm	Loss in Muzzle Velocity m/s
0	154.94	0.0
250	154.94	0.2
500	155.19	0.6
750	155.60	1.2
1000	155.80	2.0
1250	156.01	3.1
1500	156.21	4.4
1750	156.34	5.7
2000	156.54	7.0
2250	156.69	8.4
2300	156.84	9.9
2750	157.00	11.5
3000	157.12	13.0
3250	157.25	14.5
3500	157.35	15.9
3750	157.46	17.3
4000	157.56	18.7
4250	157.65	20.2
4500	157.73	21.3
4750	157.78	22.1
5000	157.84	22.9

6. *J.J. Read and J.P. Cherry, "Service Test of 155mm Howitzer, Self-Propelled, Equipped with XM185 Tube", US Army Field Artillery Board, January 1970.*

TABLE II. Chamber and Forcing Cone Dimensions for 155mm Howitzers Measured from the Rear Face of the Tube (RFT)

Cannon	Chamber Length, mm	Chamber Diametral Taper, mm/mm	Forcing Cone Diametral Taper, mm/mm	Commencement of Rifling, mm
XM185	857.5	0.0	0.10058	1010.2
M185	923.5	0.0	.20315	999.5
M199	995.9	0.00905	.10058	1054.1

II. COMPILATION OF DATA

The initial muzzle velocity and velocity at a given bore diameter are listed in Table III for the 90-, 105-, and 120-mm tank guns, the 155-mm M185 howitzer results for the XM201E2, M119, and XM201E5 charges, and the 175-mm gun. In addition, the muzzle velocity drop and the bore diameter increases normalized by dividing by initial values are given. Bore diameters represent vertical land diameter measured at the point slightly forward of the commencement of rifling that is used to determine remaining barrel life.

III. ANALYSIS AND DISCUSSION

Figure 1 compares the normalized muzzle velocity drop vs wear for the guns and howitzers listed in Table III excluding the data for the M119 charges. The interesting feature is that the curves fall into two categories with the lower corresponding to the M392 projectile fired from the M68 gun. One item that divides the guns and howitzers in Table III in the same manner as Figure 1 is the rotating band material. All projectiles listed in Table III have copper or gilding metal bands with the exception of the M392 projectile. The M392 also has an obturator which may explain why the muzzle velocity drop is lower for a given diameter increase. The apparent grouping suggests that the curve may be used as a discriminator for the reasonableness of the M119 data listed in Table I.

The M119 data are included in Figure 2. The point for cannon SN1 falls well below the results for other projectiles with metal rotating bands, while cannon SN2 falls in line with metal-banded projectiles. The point for the M119 charge taken from the firing table data is below the curve for other metal-banded projectiles, presumably because results from cannon SN1 were included in the construction of Table I. A better estimate of muzzle velocity drop vs round number could be made for the M119 charge from cannon SN2 data alone, if actual data remain unavailable. The fact that cannon SN2 data fell in line with other results for charges conditioned at 294K means the original idea of constructing Table I with muzzle velocity, bore diameter, and round number from data acquired with propellants conditioned at different temperatures was basically sound. The M119 data for cannon SN1 must be considered suspect.

Note that propellants used in firing of comparison (exp.-control) systems are generally triple-base, which have a much higher flame temp. than the double-base propellant used in the M119 prop. chg.

TABLE III. Summary of Velocity Drop for Eroded Guns

Propellant Flame temp (°K)	Caliber	Gun	Projectile	Charge	V_o,m/s	Rounds Fired	V,m/s	Diameter Increase,mm	$\Delta V/V_o$	$\Delta d/d_o$	Remarks[a,b]	Reference
M6 (?)	90mm	T139	M318	---	912.6	955	828.4	3.53	0.092	0.039	PU	c
M30 3040	105mm	M68	M392	---	1442	200	1396	3.45	.032	.033		d
M30	105mm	M68	M392	---	1442	400	1422	1.90	.014	.018	PU	d
M17 3017	120mm	T123	T116	M46	1068	300	946.7	6.35	.114	.053		c
M17	120mm	T123	T116	M46	1068	400	973.8	4.42	.088	.037	PU	c
	155mm	M126	M107	XM119E4	687.9	1896	670.9	2.01	.025	.013	TiO_2/wax	e
M30A1 3025	155mm	M185	M107	XM201E2	688.8	995	666.0	2.24	.033	.014	TiO_2/wax,CBI	f
M30A1	155mm	M185	M107	XM201E5	683.1	1201	667.5	1.78	.023	.012	TiO_2/wax	g
M6 2570	155mm	M185	M107	M119	684.3	5000	661.4	2.90	.033	.019		h
M6	155mm	XM185(SN1)	M107	M119	708.0	1000	702.3	1.90	.0082	.012	336K	i
M6	155mm	XM185(SN2)	M107	M119	715.1	995	697.1	1.90	.025	.012	336K	i
M6	175mm	M113	M437	M86A1	924.2	1000	868.1	4.70	.061	.027	TiO_2/wax	j

a - PU-polyurethane foam liner.
b - Cr-chromium-plated barrel.
c - E. Wurzel and W. Joseph, Picatinny Arsenal Technical Report No. 2710, March 1961.
d - R.O. Wolff, Picatinny Arsenal Technical Report No. 3096, August 1963.
e - J.S. Whitcraft, DPS Report No. 1646, July 1965.
f - Reference 2.
g - M. Kahn, "First Letter Report of Development Test II - Wear Phase of Propelling Charge, 155mm, XM201E5", July 1977.
h - Reference 1.
i - Reference 5.
j - D.M. Roeck, Watervliet Arsenal Technical Report No. 6750, December 1967.

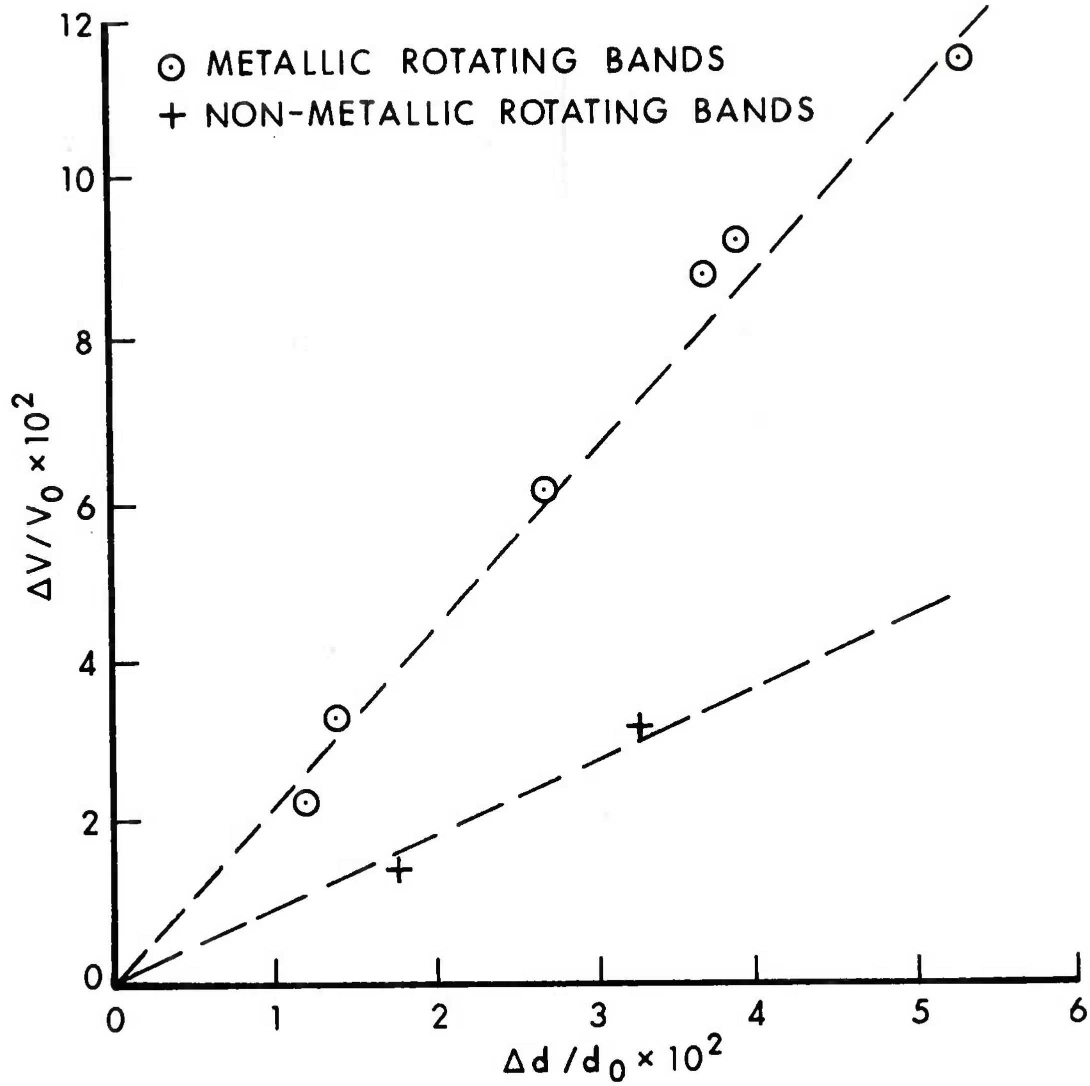

Figure 1. Muzzle Velocity Drop vs Bore Diameter Increase

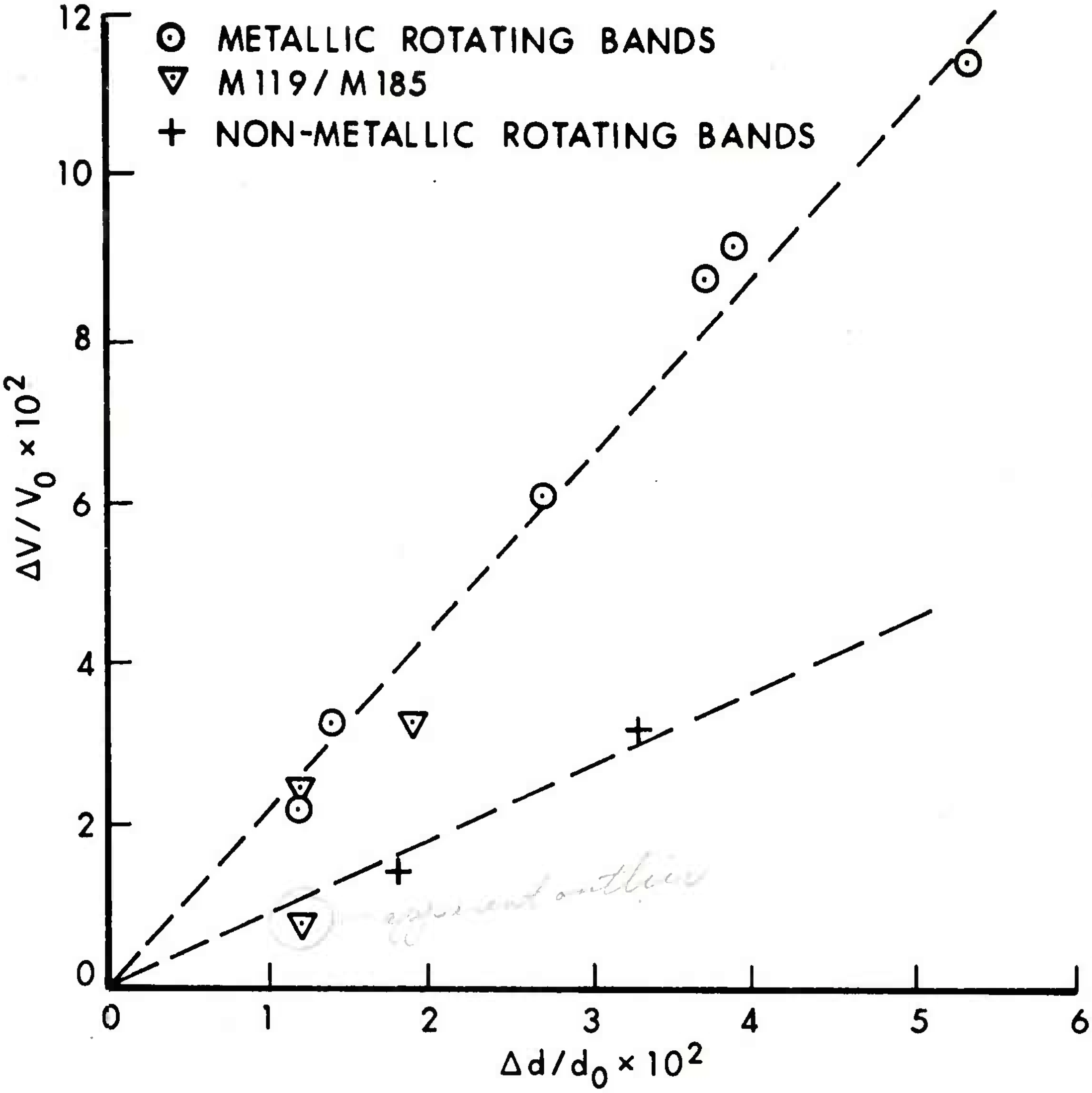

Figure 2. Muzzle Velocity Drop vs Bore Diameter Increase
Including M119 Firing Table Data

A chance to check this hypothesis in another cannon arises from combining M199 tube wear test data[7] and tube fatigue test data[8]. The fatigue test was done with XM123E2 propelling charges conditioned at 336K firing M549 RA projectiles; the wear test was performed with the M203 charge conditioned at 294K firing the M549 RA projectiles. The M203 charge is ballistically equivalent to the XM123E2 charge.

Figure 3 depicts muzzle velocity of the M549 RAP as a function of land diameter increase of the M199 cannon. In Figure 4, the muzzle velocity drop is plotted vs land diameter increase. The muzzle velocity drop at a given land diameter increase is the same for M549 projectiles fired with propellant conditioned at either 336 or 294K, especially when one considers the uncertainty of the muzzle velocity drop is three metres/second. One can also see in Figure 4 that the difference in muzzle velocity of cannons 44 and 45 at a given bore diameter is never as great as that seen in XM185 cannons 1 and 2. This would tend to rule out tube to tube variability as the reason for the discrepancy in muzzle velocity drop at 1.90-mm wear in the two XM185 cannons.

More interesting, perhaps, is the comparison of the M199 data with the results in Table III. The corresponding results for the M199 cannon are listed in Table IV.

TABLE IV. Muzzle Velocity Drop vs Land Diameter for the M199 Cannon Firing M549 RA Projectiles at Zone 8

Cannon	V_o, m/s	Δd, mm	V, m/s	$\Delta V/V_o$	$\Delta d/d_o$	Round Number
44	856.2	2.13	845.8	0.012	0.014	727
45	855.6	1.98	845.5	.013	.013	791
77	828.1	2.16	816.9	.014	.014	1527

First, one notices the ratio of muzzle velocity drop to initial velocity and land diameter increase to initial diameter is the same for the rounds fired with charges conditioned at each temperature, in contrast to the two XM185 cannons. Second, one notes that the values of $\Delta d/d_o$ equal to 0.014 are in line with those for the M392 projectiles fired with additive from the M68 cannon. For a given amount of erosion, the muzzle velocity drop of the M549 projectile fired from the M199 cannon is half the drop in velocity for other projectiles with metal rotating bands.

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7. *J.D. Kruger, "DTII of Howitzer, 155mm Towed, XM298 (Tube Wear Phase with the XM203 Propelling Charge)", YPG Firing Report No. 13703, May 1976.*

8. *J. Callicotte, "155mm Howitzer Tube, XM199, Tube Fatigue/Life Test", YPG Firing Report No. 13655, April 1975.*

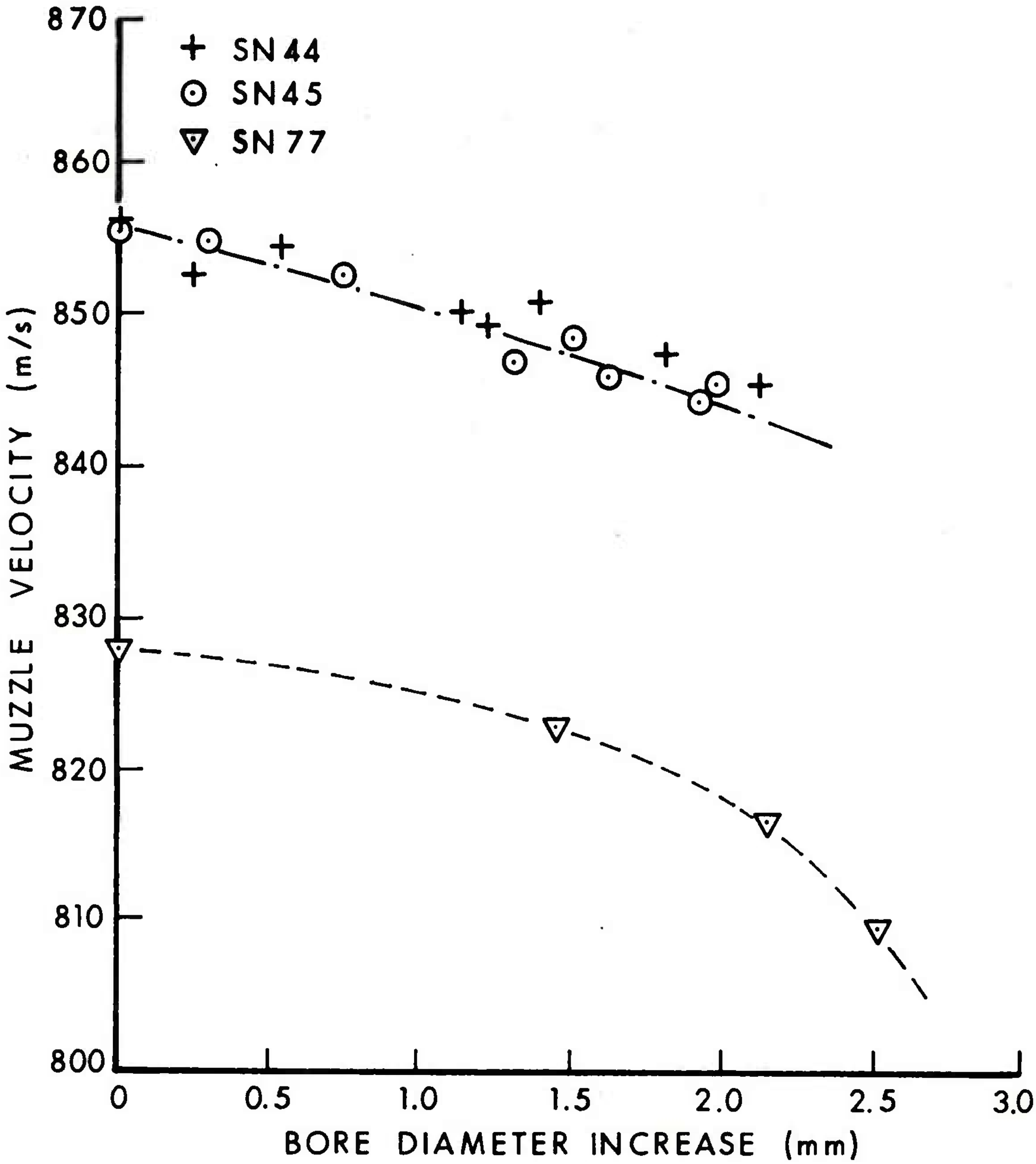

Figure 3. Muzzle Velocity of M549 RAP Fired from the M199 Cannon

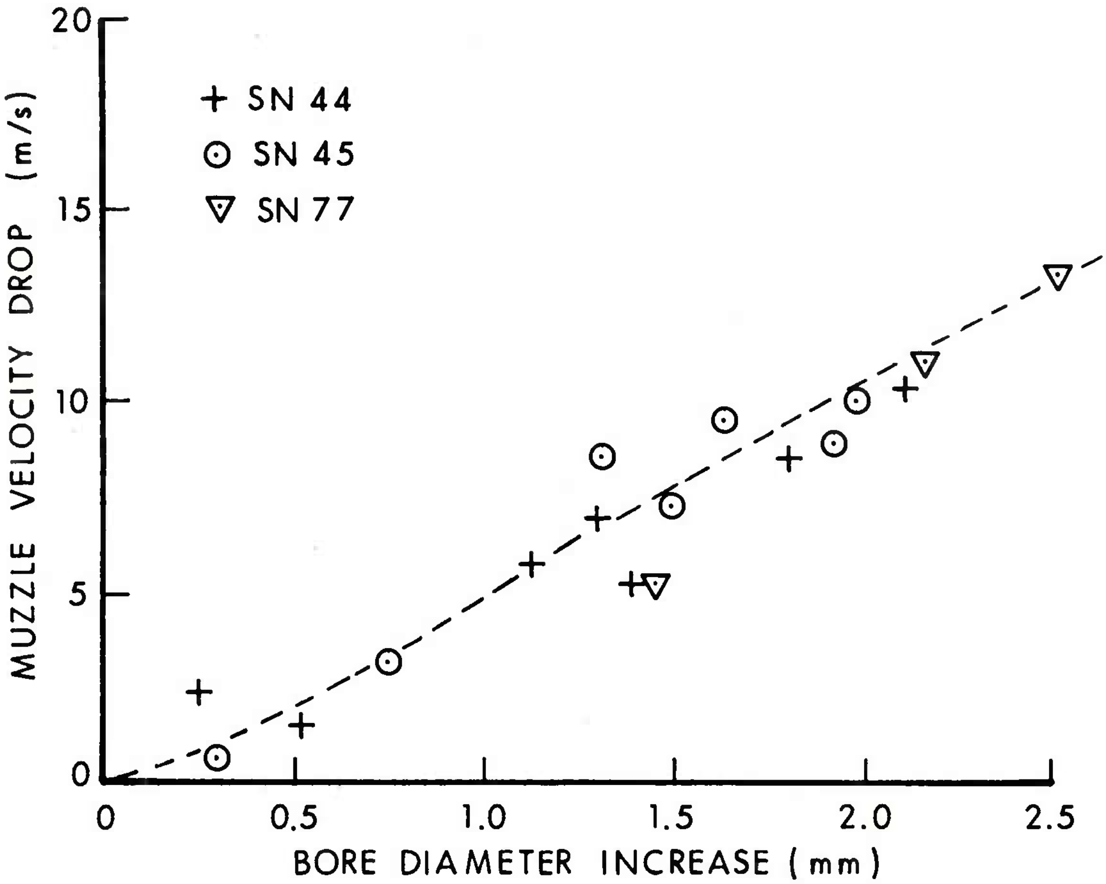

Figure 4. Muzzle Velocity Drop of M549 RAP Fired from the M199 Cannon

As noted earlier, better obturation is cited as one reason for less decay in muzzle velocity for the M392 projectile. The M549 RA projectile has an obturating band which may account for the seemingly low muzzle velocity drop. Another factor may be the unusual erosion pattern of the M199 cannon. Figure 5 depicts the vertical land diameter increase and vertical groove diameter increase for the M199 cannon. One sees that the grooves erode little, if at all, during the time the lands are completely removed (2.54-mm). After the lands have been removed, the grooves begin to wear at the same rate. The rate of velocity drop vs bore diameter begins to increase as shown below for cannon SN77.

V_o, m/s	Δd, mm	V, m/s	$\Delta V/V_o$	$\Delta d/d_o$	Round Number
828.1	2.16	816.9	0.014	0.014	1527
828.1	2.52	809.8	.022	.016	2001

This suggests the wear pattern rather than presence of the obturator on the M549 projectile might account for the lower rate of velocity drop relative to the degree of barrel wear.

A chance to test the hypothesis that better obturation of the M107 projectile might reduce the muzzle velocity drop in half arose during testing of the XM201E5 charge[9]. This is the designation for the improved XM201E2 charge with the black powder and with an additional TiO_2/wax liner. Muzzle velocities of the M107, M549, and M483A1 projectiles were taken at the start of testing and at various points during the wear test. The obturating bands from the M549 and the M483A1 projectiles were put on the M107 to test how much the velocity drop of the M107 could be reduced at a given bore diameter. The pertinent data are summarized in Table V. One sees that the obturator from either projectile raises the muzzle velocity of the M107 projectile when fired from a worn M185 cannon. The M483A1 obturator is slightly better than the obturator from the M549 RAP. Since the M483A1 obturator has a larger diameter, one would expect the M483A1 to be a slightly better obturator. The gain in muzzle velocity doesn't seem significant enough to justify obturators on M107 projectiles. Table V also shows the muzzle velocity drop is even less for the M549 RAP and M483A1 projectiles at the same stage of tube wear as the M107 projectile with obturator. In view of the limited value of the obturator on the M107 projectile, one would suspect the rotating band design would be more crucial to maintaining muzzle velocity.

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9. *M. Kahn, "First Letter Report of DTII Wear Phase of Propelling Charge, 155mm XM201E5", Materiel Testing Directorate, APG, MD, July 1977.*

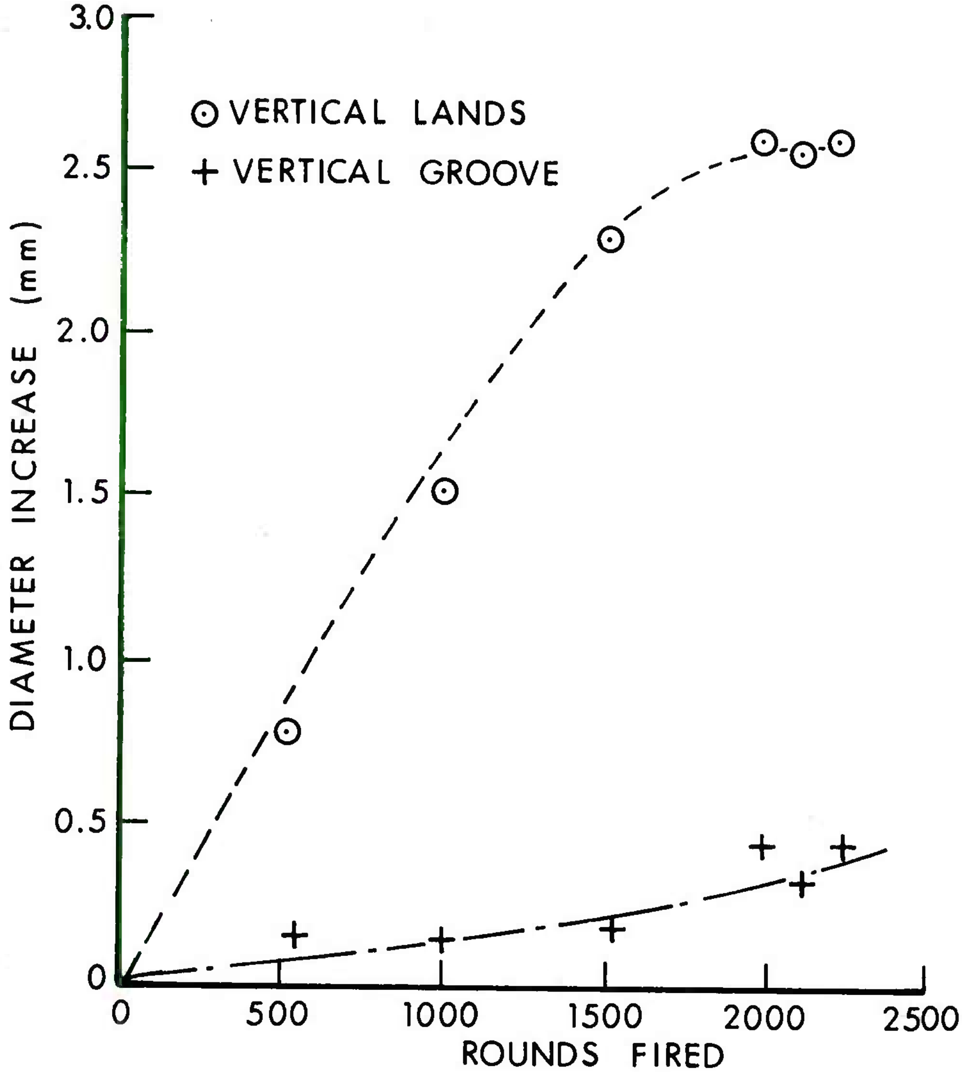

Figure 5. Wear Profile of the M199 Cannon Firing Zone 8 Charges

The exceptions numerated here show the curve in Figure 1 for metal-banded projectiles is not universal. As a minimum, rotating band design, presence of obturator bands, and tube wear pattern need be considered. For projectiles with similar rotating band design, the correlation in Figure 1 is a convenient way to discern anomalies, e.g., the firing table data for the M119 charge appear to underestimate the muzzle velocity drop.

TABLE V. Muzzle Velocity *vs* Land Diameters for Projectiles Fired from a M185 Cannon with XM201E5 Charges[a]

Diameter Increase,mm[b,c]	Rds	Muzzle Velocity, m/s M107	M549	M483A1	M107[d] (white)	M107[e] (gray)
0	0	683.1	680.3	652.9	-----	-----
1.24	719	676.7	672.1	648.6	-----	-----
1.88	1301	669.0	-----	647.4	-----	-----
2.59	2089	654.4	-----	-----	656.5	659.0
2.69	2364	649.8	-----	641.3	648.6	653.8
3.05	2814	643.1	-----	640.7	642.8	650.8
3.23	3224	638.2	-----	-----	643.4	648.0
3.38	3468	642.8	646.8	637.0	-----	-----

a - Wear pattern produced with M107 projectile.
b - Vertical land diameter increase measured 1005.8-mm RFT.
c - Initial diameter 155.04-mm.
d - Obturator from M549 RAP.
e - Obturator from M483A1 projectile.

IV. CONCLUSIONS

1. The ratio of muzzle velocity drop/initial muzzle velocity correlates well with land diameter increase/initial land diameter for a number of wear-limited Army guns. All exceptions noted to the correlation were for obturated projectiles or for projectiles fired from the M199 cannon. In this cannon, the grooves do not wear until the lands disappear which should reduce gas blowing by the projectile as a function of the land erosion. After complete land erosion, blow-by should increase.

2. Of the two XM185 cannons from which the muzzle velocity drop for the M119 charge was estimated as a function of tube wear, one tube had significantly lower muzzle velocity drop than the drop predicted from the above correlation. The data in the 155mm firing table for M119 muzzle velocity drop *vs* rounds may underestimate the actual muzzle velocity drop.

3. An obturator placed on the M107 projectile to reduce muzzle velocity drop did indeed raise the muzzle velocity of the M107 projectile when fired from a worn cannon. The increase was not as great as that for M483A1 or M549 RA projectiles with oversized rotating bands as well as obturators. This suggests the rotating band design is more important than the obturator in reducing the rate of muzzle velocity drop as the gun tube wears. It also suggests that band diameter must be considered to obtain a universal plot of normalized wear vs velocity loss.

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